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The effects of predictive solutions on training time and post-training performance for control systems with human operators.

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THE EFFECTS OF PREDICTIVE SOLUTIONS ON TRAINING TIME AND POST-TRAINING PERFORMANCE FOR CONTROL SYSTEMS WITH HUMAN OPERATORS

by

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THESIS

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ON TRAINING TIME AND POST-TRAINING PERFORMANCE
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David Lee Myers

June 1969

The Effects of Predictive Solutions

On Training Time and Post-Training Performance

For Control Systems with Human Operators

by

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Lieutenant(junior grade), United States Navy
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ABSTRACT

The effect of predictive solutions on human operator training time and post-training performance in a complex manual control system has been investigated. A control system with a slow and complex response to the input signals was formulated. Fifty operators, 25 with the aid of predictive solutions and 25 without the predictive solutions, were tested and the mean performance of each group was compared to that of the other.

There was a significant improvement in the training time when the predictive solutions were provided. The improvement was directly proportional to the complexity of the system. The greater the initial challenge of the system, the greater was the worth of the predictive solutions. The post-training performance was better by a factor of two when the predictive solutions were available to the operator. The performance of the operators without the aid of predictive solutions remained inconsistent even after a steady-state performance had been reached.

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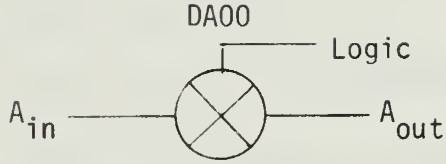
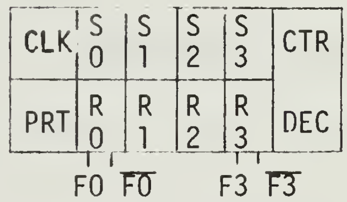
TABLE OF SYMBOLS AND ABBREVIATIONS

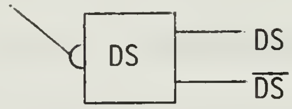
DIGITAL/ANALOG SWITCH



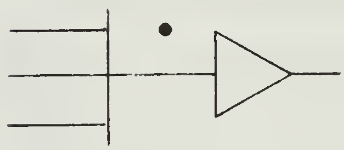
4-BIT DECIMAL COUNTER



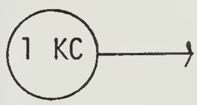
LOGIC SWITCH



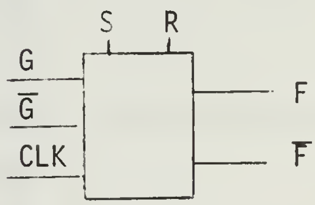
NAND GATE



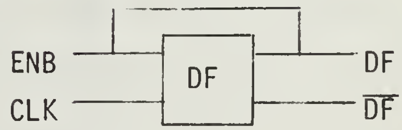
CLOCK



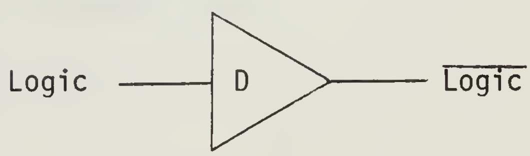
FLIP-FLOP



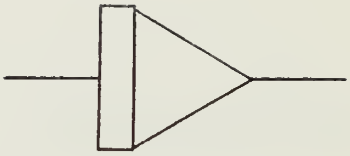
DELAY FLOP



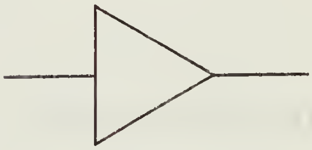
DRIVER



INTEGRATOR



INVERTER OR AMPLIFIER



POTENTIOMETER

A/D	Analog-to-digital
CLK	Clock
CTR	Counter
D	Driver
DA	Digital/analog switch
D/A	Digital-to-analog
DEC	Decimal
DF	Delay Flop
DS	Digital switch
ENB	Enable
FF	Flip-flop
FT	Fast-time solution
G	Gate
IC	Initial condition
P	Potentiometer
PRT	Preset counter
R	Reset
RTO	Real-time-only solution
S	Set
SJ	Summing junction
T	Trunk
X_{ft}	X(fast-time)
Y_{ft}	Y(fast-time)

I. INTRODUCTION

The need for highly competent human operators in vehicular control and navigation systems has become pronounced in today's technology. The military and the aerospace program in particular involve human operators in many complex control systems. Missile guidance and spacecraft control are prime examples of this type of system.

In a complex manual control system with a long training period, a human operator should be able to attain a competent level of performance in a shorter time interval with the aid of predictive solutions. After the operator's training is completed, he should then be able to perform as well without the predictive solutions, but in more complex systems it might prove necessary to utilize the predictive solutions in order to maintain an acceptable performance level. In 1954 Ziebolz and Paynter discussed the possibility of two-time scale automatic control systems in which predictive information about the future performance of the process under control was computed [Ref. 4]. In 1963, simulating space ship moon landings, L.C. Fargel and E.A. Ulbrich proved that predictive display markedly improved the learning period when using simple inputs. The performance measure Fargel and Ulbrich tested was the quantity of fuel consumed. Their work is in Ref. 3.

For predictive solutions to be of value, the system's response needs to be a slow and complex function of the input signal. If this is not true, the operator can easily master the system without the predictive solutions, and the predictive solutions would be a wasted expense. Also the response of the system should not be easily

describable by the operator. More work needs to be done in this field in order to establish exactly when a predictive solution system can be employed economically and practically, and effectively reduce the training time of an operator, as well as improve his post-training performance.

II. NATURE OF THE PROBLEM

The objective of the problem was to investigate the use of predictive solutions in the training and performance of human operators. The problem was formulated such that the actual training period and the post-training performance were of primary consideration. Fuel consumption and other criteria were completely disregarded. A hybrid computer was used for control and simulation of the real-time and fast-time systems.

A complex manual control system whose response to the input controls was slow and not readily learned by a human operator had to be formulated. The system selected was a two-axis system in which the operator was required to place a movable point as close as possible to a target at the end of a specified time interval. The first candidate's dynamics (see Fig. 1) were found unsatisfactory; the response of the system to the input control was too fast and not complex to any degree. For the second candidate (see Fig. 2) the response was slow, particularly when the velocity of the point was large, and was a more complex function of the input. This system was selected.

Seven trial human operators were then observed and each was given different magnitudes of control. It was discovered that the magnitude of the control had to be kept small. This was so because if the control was too great, the operator could easily overcome any complexity in the system by sheer force. When the control was made too small, however, it became impossible for the operator to accomplish his mission. By comparing the performance of the operators tested, a degree of control

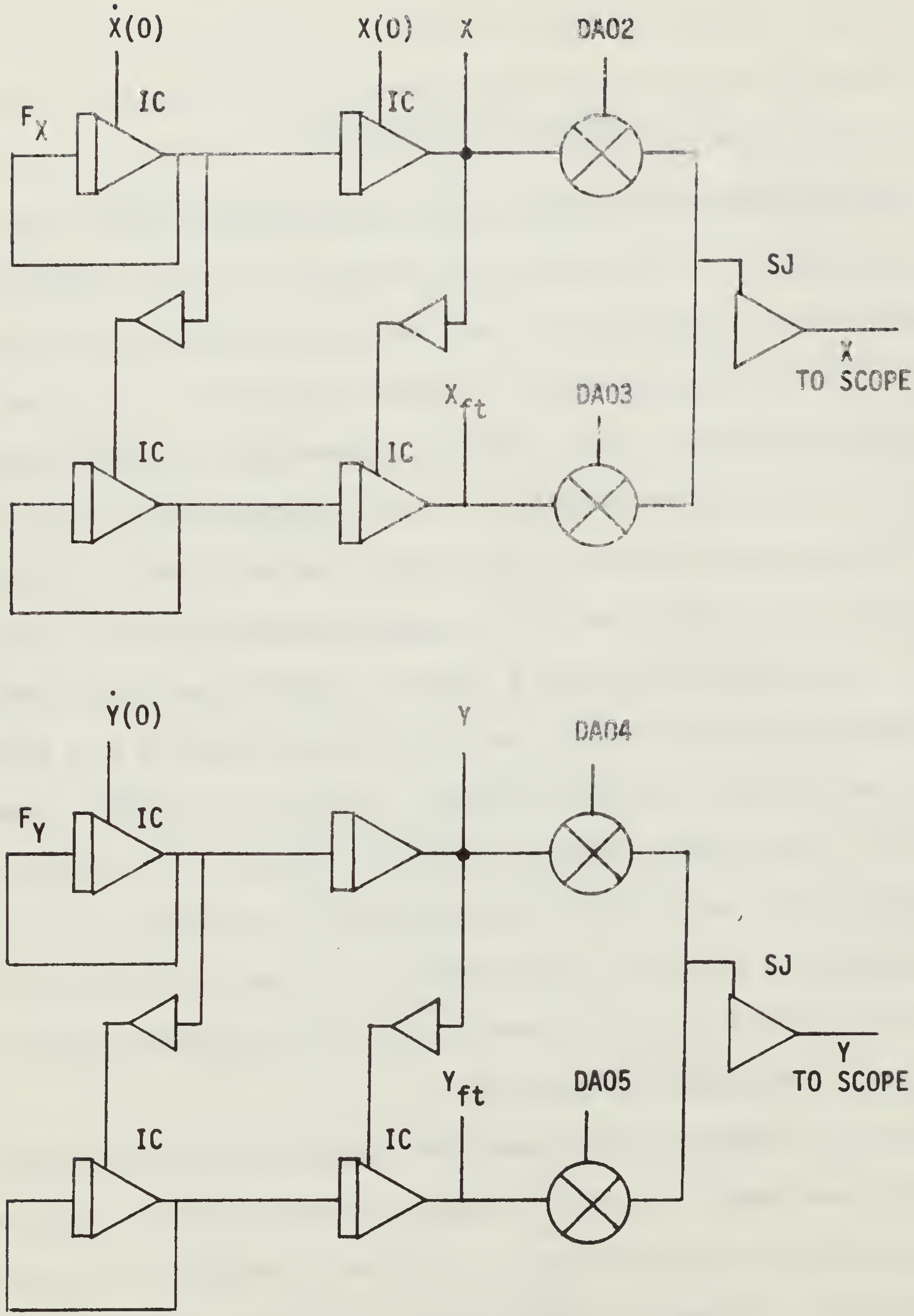


Fig. 1. ORIGINALLY PROPOSED CONTROL SYSTEM

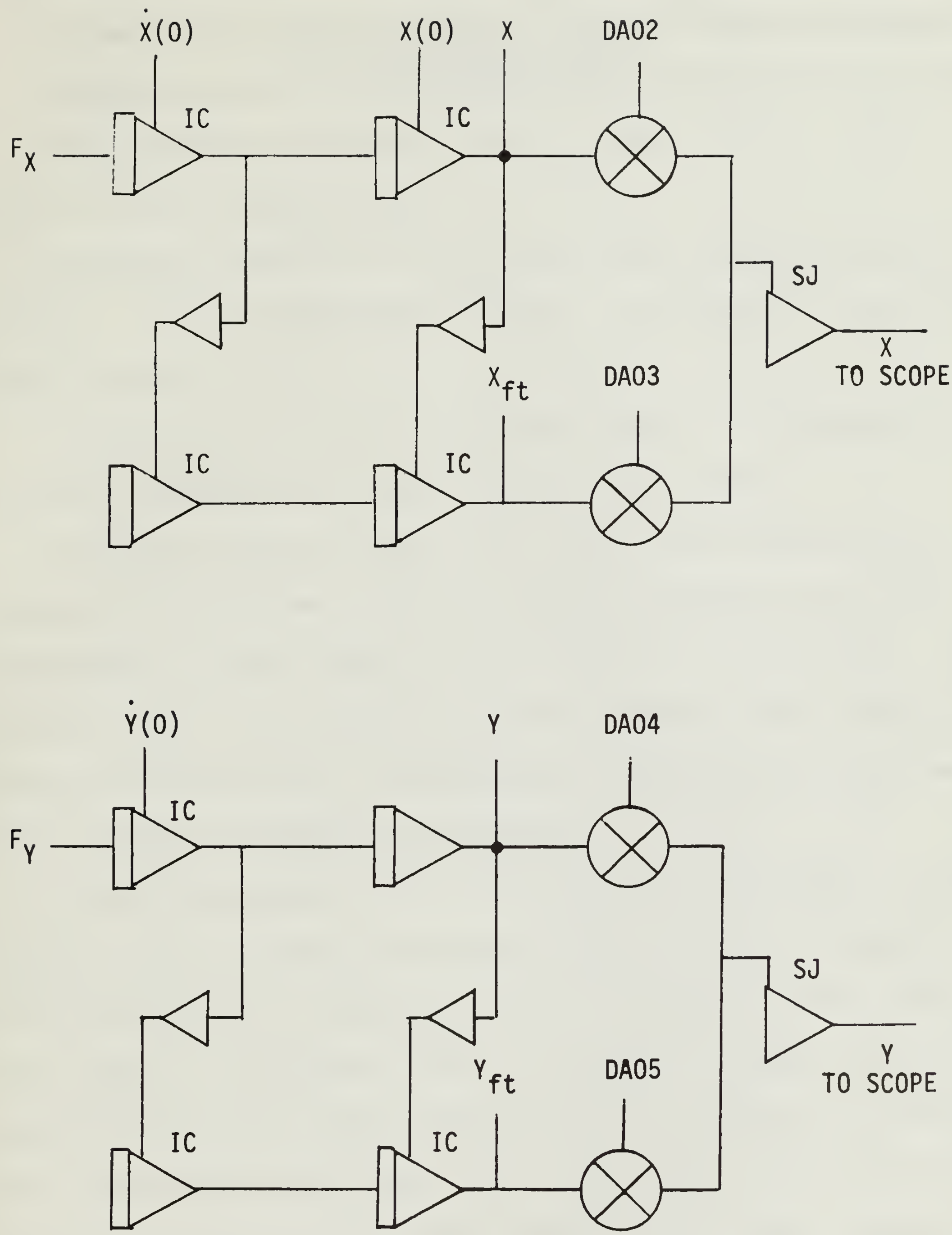


Fig. 2. SELECTED CONTROL SYSTEM

was selected such that after the operator had learned the system he could easily achieve his goal no matter what the initial conditions were, but also such that the response was still slow and complex.

III. THE CONTROL SYSTEM

A block diagram of the entire system is shown in Fig. 3. Each section is fully explained below.

The display consists of an oscilloscope which displays two separate solutions, the fast-time and the real-time. The operator's view of the scope is shown in Fig. 4.

The next section consists of the human operator. His purpose was to observe the display and adjust the controls as needed.

The control section is made up of a chair with a control stick mounted on the right arm. Forward and backward motion on the stick corresponded to forces in the +Y and -Y directions, respectively. Right and left motion on the stick corresponded to forces in the +X and -X directions, respectively. The magnitude of the forces was linear between extremes in movement of the controls.

The real-time segment is the next component of the system. It is comprised of two sections, the digital and the analog. A schematic of the analog section is shown in Fig. 2. A schematic of the analog logic control is displayed in Fig. 5. The X and Y systems were identical except that the initial condition of the Y integrator was always zero. The transfer functions of X and Y were $1/S^2$. The X and Y forces were the only inputs to the system other than the initial conditions. A compute time of sixteen seconds was selected. Shorter (faster) tasks are outside the realm of human ability to follow, react, or anticipate. Sixteen seconds is a reasonable length both from a human point of view and

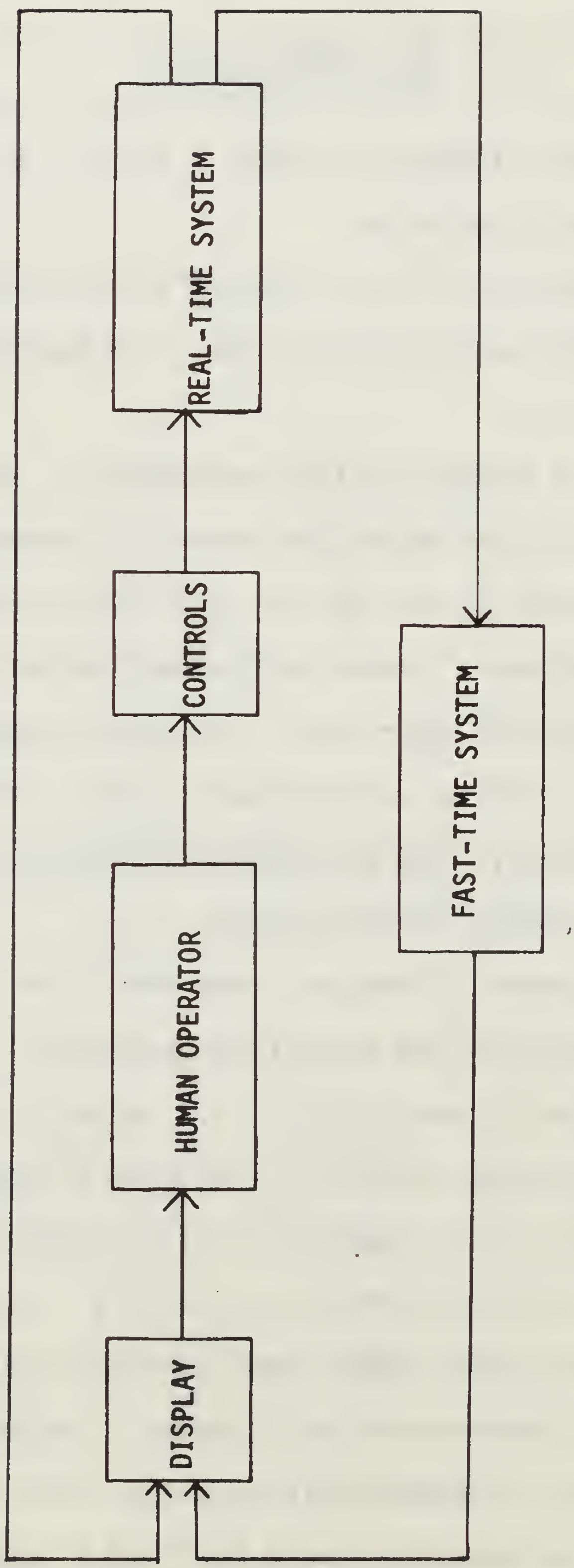


Fig. 3. BLOCK DIAGRAM OF THE TOTAL SYSTEM

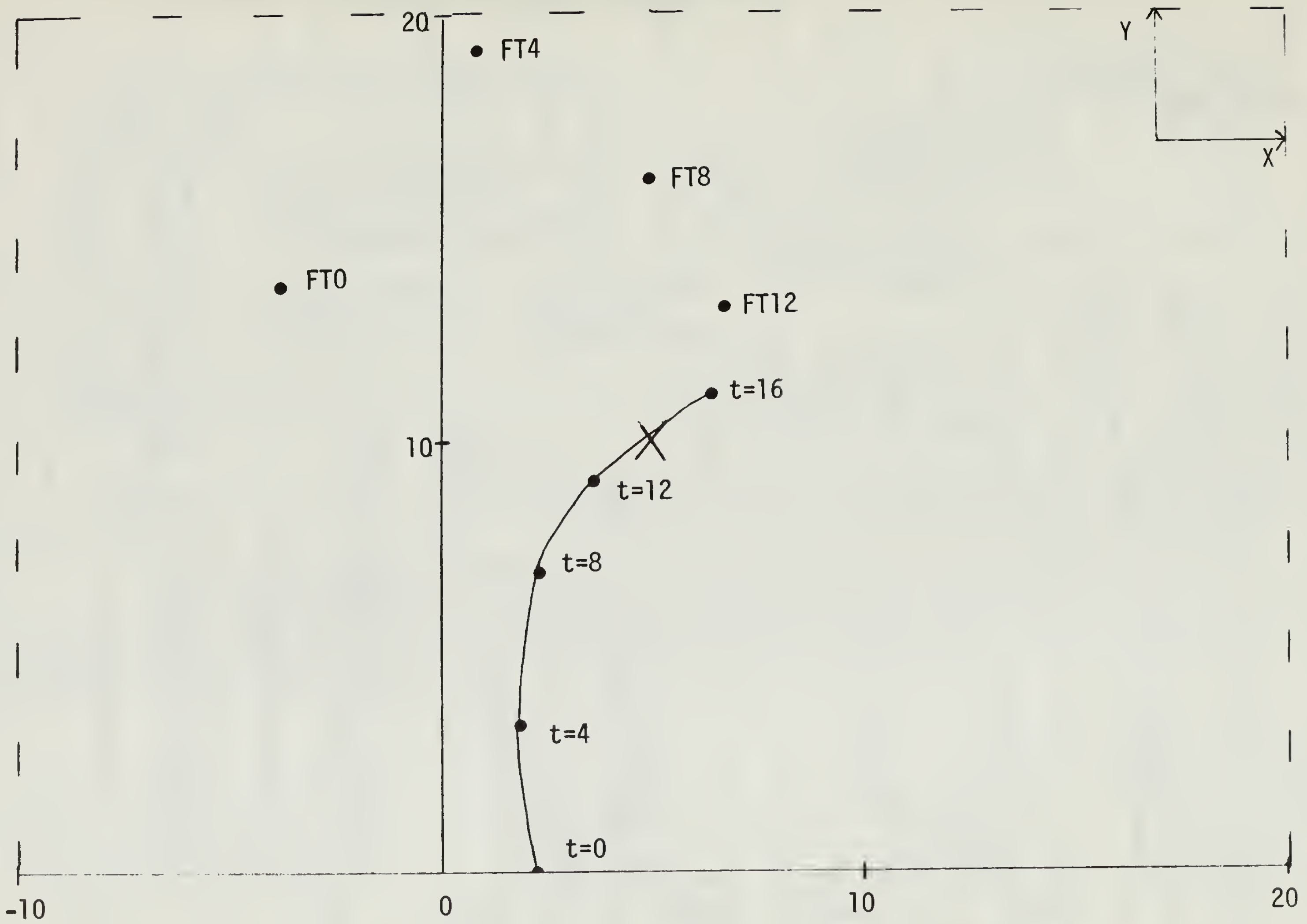


Fig. 4. OPERATOR'S VIEW OF THE OSCILLOSCOPE

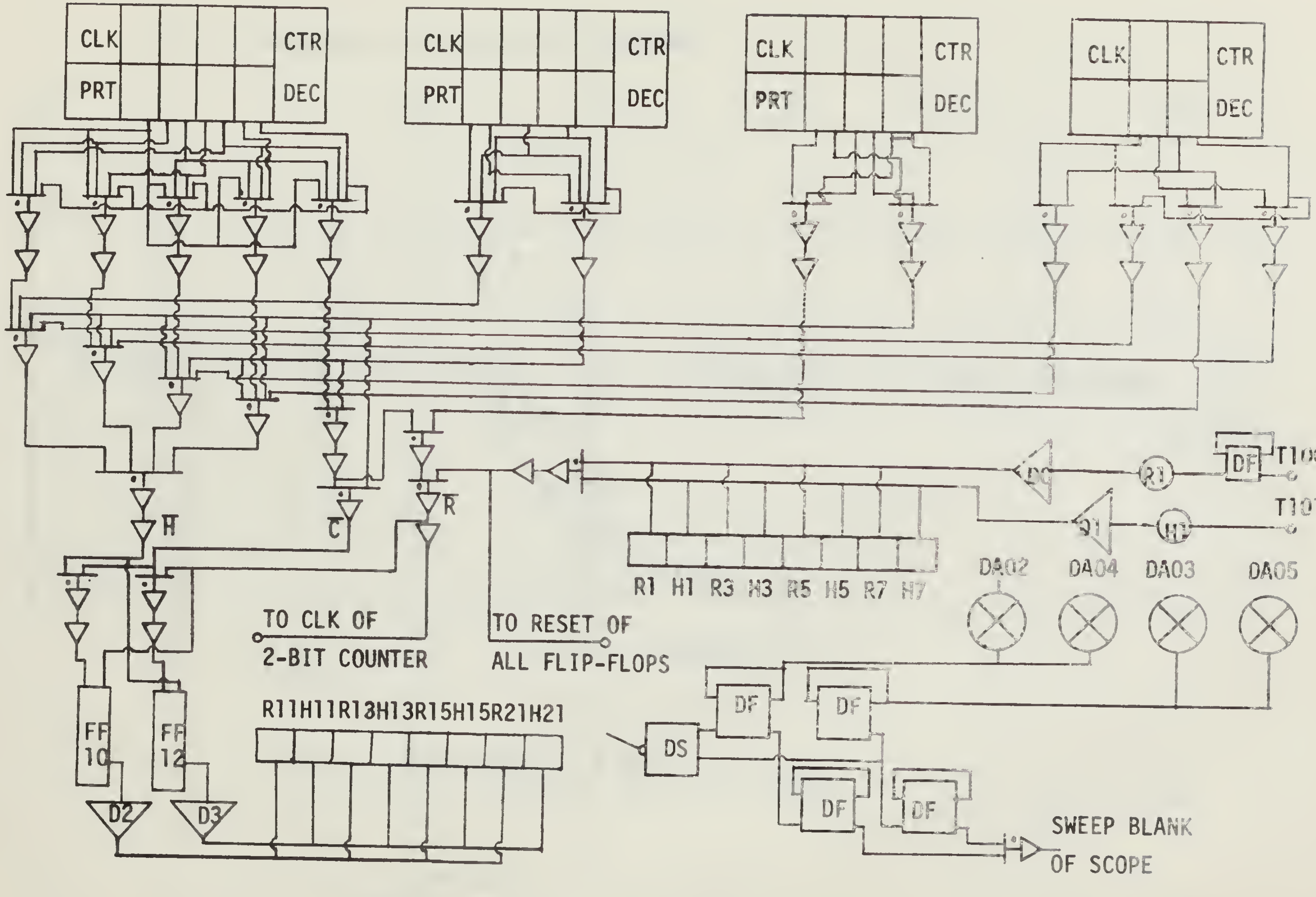


Fig. 5. SCHEMATIC OF ANALOG CONTROL LOGIC

from computer simulation time requirements. The output of the X and Y integrators on the analog computer were continuously fed to the display section.

The analog logic control was designed to provide accurate results for the predictive solutions, to yield the real-time compute cycle, and to allow the display of the two solutions simultaneously. The real-time system was operated in clock mode, with sixteen seconds in compute and then one-half second each in reset and hold. The logic for the display is explained in Appendix A. The fast-time control consisted of two counters, a 400-decimal counter and a four-decimal counter. The 400 counter was driven by a 100 cycle per second clock which yielded a four-second clock. This counter was a preset counter which was reset each time 400 counts were reached. By the use of nand gates, the logic was constructed such that two flip-flops were driven by pulses which were true when either compute, reset, or hold were needed on the fast-time integraters. The outputs of these flip-flops were inverted and inputed to two drivers, which in turn went to the integraters. These fast-time integraters were 100 times faster than the real-time integraters. The 400 counter drove the four counter once each cycle. This counter was needed in order to readjust the compute time to account for the time already expired in the real-time cycle.

The digital section had four functions. The first was control of the analog computer. The second function was the selection of random values for the initial conditions of X, the velocity of X, and the velocity of Y. The recording of the final value of X and Y was the third purpose. The last task of the digital computer was to calculate

the error for each run, the challenge level of the initial conditions, and to store this data on magnetic tape for later analysis. A flow chart of the main program is shown in Fig. 6.

The initial conditions were uniformly distributed independent random variables with ranges as follows:

$$0.0 \leq X(0) \leq 10.0$$

$$-1.25 \leq \dot{X}(0) \leq 1.25$$

$$0.0 \leq \dot{Y}(0) \leq 1.25$$

These limits were selected for two reasons, the first being the elimination of scaling problems on the analog computer and the second being the need to have the first fast-time solution appear on the scope. The initial conditions were determined randomly in order to increase the challenge of the control problem to the human operator, and to eliminate the possibility of rapid adaptation to a single set of initial conditions by any operator.

The next segment of the control system was the fast-time solution. The fast-time system was exactly identical to the real-time system except that it was run 100 times faster. There was no input to the fast-time system other than initial conditions. The initial conditions were taken directly from the real-time system, X(0) from the X output of the real-time system, etc.

There were four fast-time solutions displayed at four-second intervals during the sixteen second real-time compute cycle. The first was shown at 0.16 seconds, the second at 4.12 seconds, the third at 8.08 seconds, and the fourth at 12.04 seconds. Each was displayed until one second

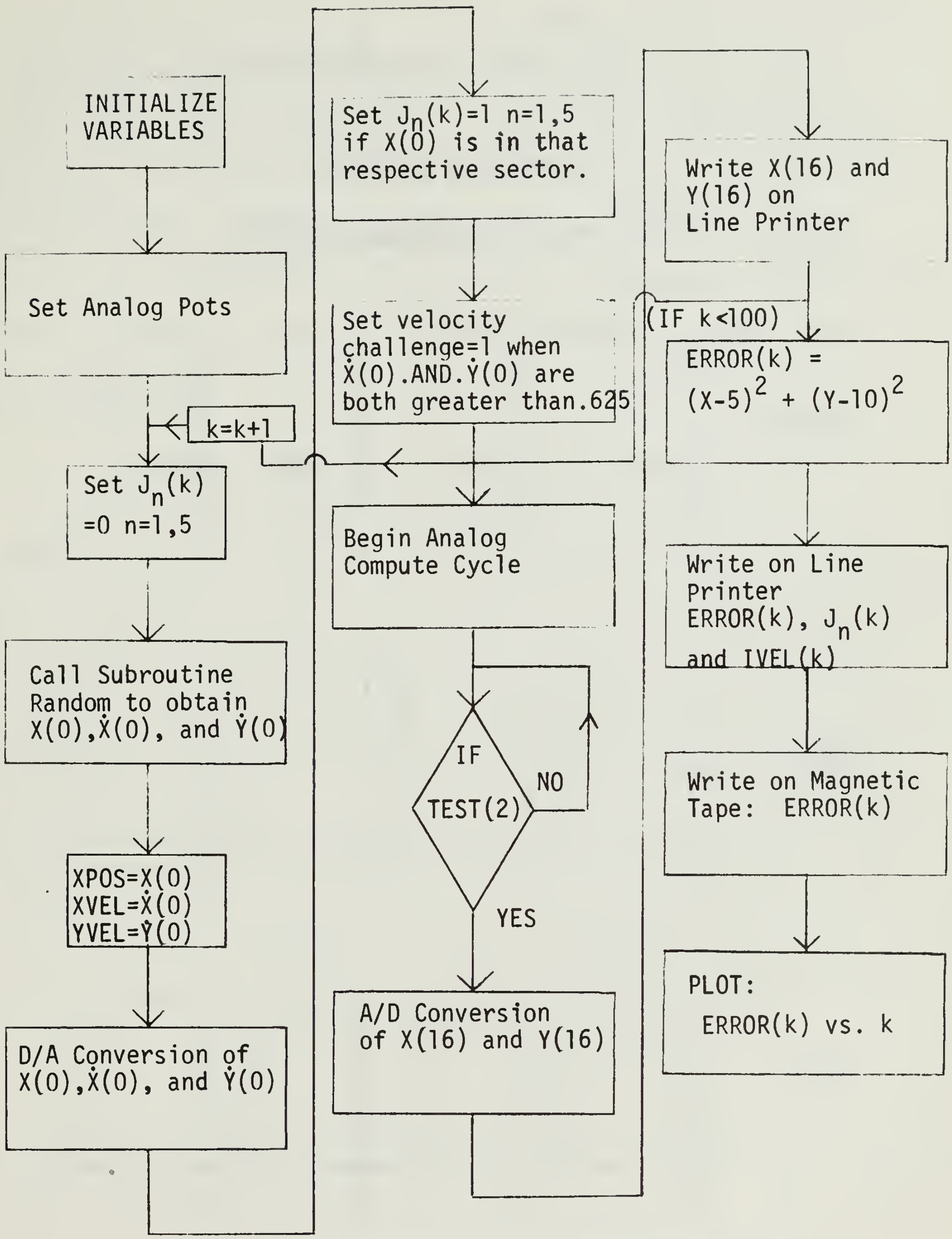


Fig. 6. FLOW CHART FOR MAIN PROGRAM

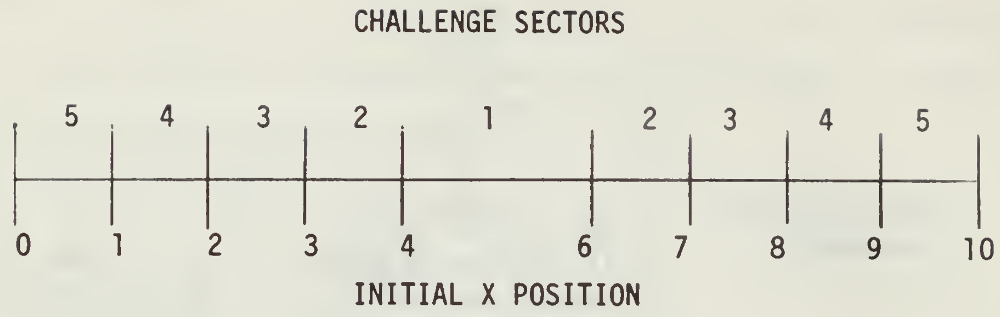


Fig. 7. INITIAL POSITION CHALLENGE SECTORS

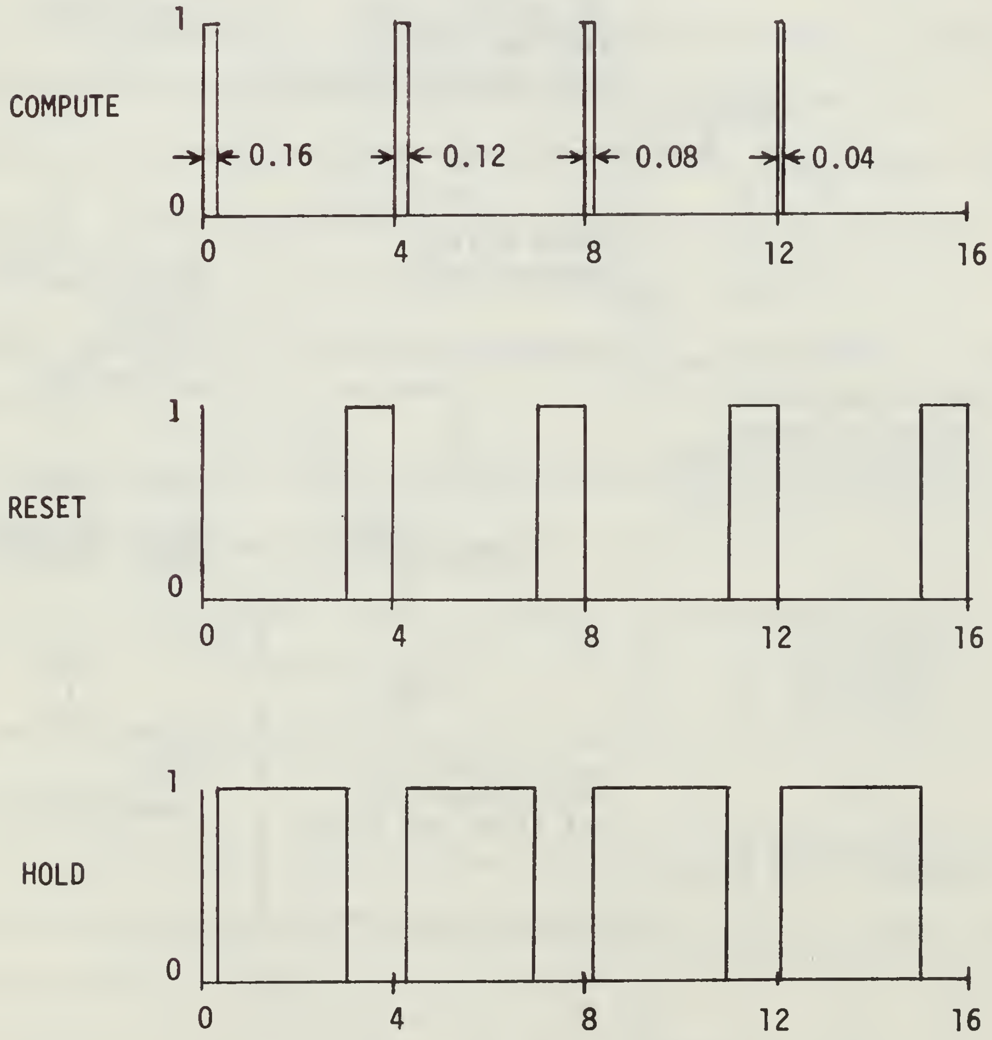


Fig. 8. ILLUSTRATION OF FAST-TIME CYCLE

before the next fast-time solution was to be computed. At that time the fast-time system went into reset for one second. Graphs of the compute, reset, and hold cycles are displayed in Fig. 8.

The fast-time display showed the human operator exactly what the state of the system would be at the final time (t = 16 seconds) if he applied no further controls throughout the rest of the real-time solution. This enabled the operator to see and determine the direction in which to move the control stick and to estimate how much control he should apply.

IV. EXPERIMENTAL PROCEDURE

In order to obtain meaningful data a large number of human operators had to be tested. To enable investigation of improvement in training times, equal numbers of operators using predicted solutions and not using predicted solutions had to be used. It was decided to have 50 operators, 25 with fast-time solutions displayed and 25 without the aid of fast-time solutions.

Of the operators tested, there were: 23 graduate students, all of whom were naval officers, 22 electronic laboratory technicians, two computer supervisors, one professor in electrical engineering, and two computer technicians. Each operator made 100 separate runs of the problem. This number was decided upon as a result of observing the seven trial operators, whose average training period was about 80 runs.

No operator was allowed any trial runs. Each operator was given the following information: the objective is to be at the target at the end of 16 seconds; there will be 100 runs with one-second reset time between runs; the operation of the controls was explained; the response is slow; the initial conditions are random. The operators who were given the fast-time solutions were also explained their meaning and method of display.

V. ANALYSIS OF DATA

The final position at the end of each run and the initial challenges were the only data used to analyze the performance of the human operators. The final position was used to compute the error of the run. The error was defined as follows:

$$\mathrm{ERROR}(K)=(X-5)^2 + (Y-10)^2. \qquad (1)$$

This is the square of the distance from the final position to the target. It was squared because negative error was considered to be of consequence equal to that of positive error. The error of each run was stored on magnetic tape so it could be later processed.

In order to reinitialize the subroutine that produced the random initial conditions, it was necessary to recompile the main program immediately before each operator began his runs. Each operator therefore, was presented with exactly the same sequence of sets of initial conditions as was every other operator. This allowed for direct comparison of all human operators.

Due to the random initial conditions, the difficulty of control varied. The level of difficulty was called the initial challenge. Two types of challenge were present. These were an initial position challenge and an initial velocity challenge.

There were five degrees of initial position challenge. The least challenge (first degree) was considered to be that case where the initial position in X was in the center of its range, or in other words, directly under the target. The degree of challenge increased as the initial position moved to either of its extremes (fifth degree was designated the greatest challenge). The challenge sectors are shown in Fig. 7.

The other type of initial challenge was associated with velocity. A velocity challenge was defined to exist when the magnitudes of both $\dot{X}(0)$ and $\dot{Y}(0)$ were greater than one-half their maximum possible value.

After the 50 operators had been tested, the data was kept in two separate groups, the fast-time operators and the real-time-only operators. The mean value, the variance, and the standard deviation for each of the 100 runs for each group of 25 were calculated as follows:

$$\mathrm{MEAN}(K)=[\sum_{KK=1}^{25} \mathrm{ERROR}(K,KK)]/25.0 \qquad (2)$$

$$\mathrm{VAR}(K)=\sum_{KK=1}^{25} [\mathrm{ERROR}(K,KK)-\mathrm{MEAN}(K)]^2 \qquad (3)$$

$$\mathrm{STDEV}(K)=[\mathrm{VAR}(K)]^{1/2} \qquad (4)$$

The maximum error and the minimum error for each run were also computed.

Graphs of every possible combination of the velocity and position challenges were then plotted. These graphs each contained five separate curves. The abscissa for all five curves was the run number, K. The five ordinates were the maximum error, the mean value plus the standard deviation, the mean value, the mean value minus the standard deviation, and the minimum error. These same five curves were also plotted in a summary graph which included all 100 runs no matter what the initial condition was. Another plot of the mean value versus the run number for all runs was made. This made a total of 19 graphs per group. These 38 graphs were then examined to observe whether or not the predictive solutions aided the operator and if so how much. The possibility of different training times for the various combinations

of initial conditions was also investigated. The most illustrative of these graphs are shown in Figs. 10-19. The flow chart for plotting these graphs is shown in Fig. 9.

The post-training performance of the two groups was analyzed to determine if the fast-time solutions would be required to maintain an acceptable steady-state performance after the training period was completed.

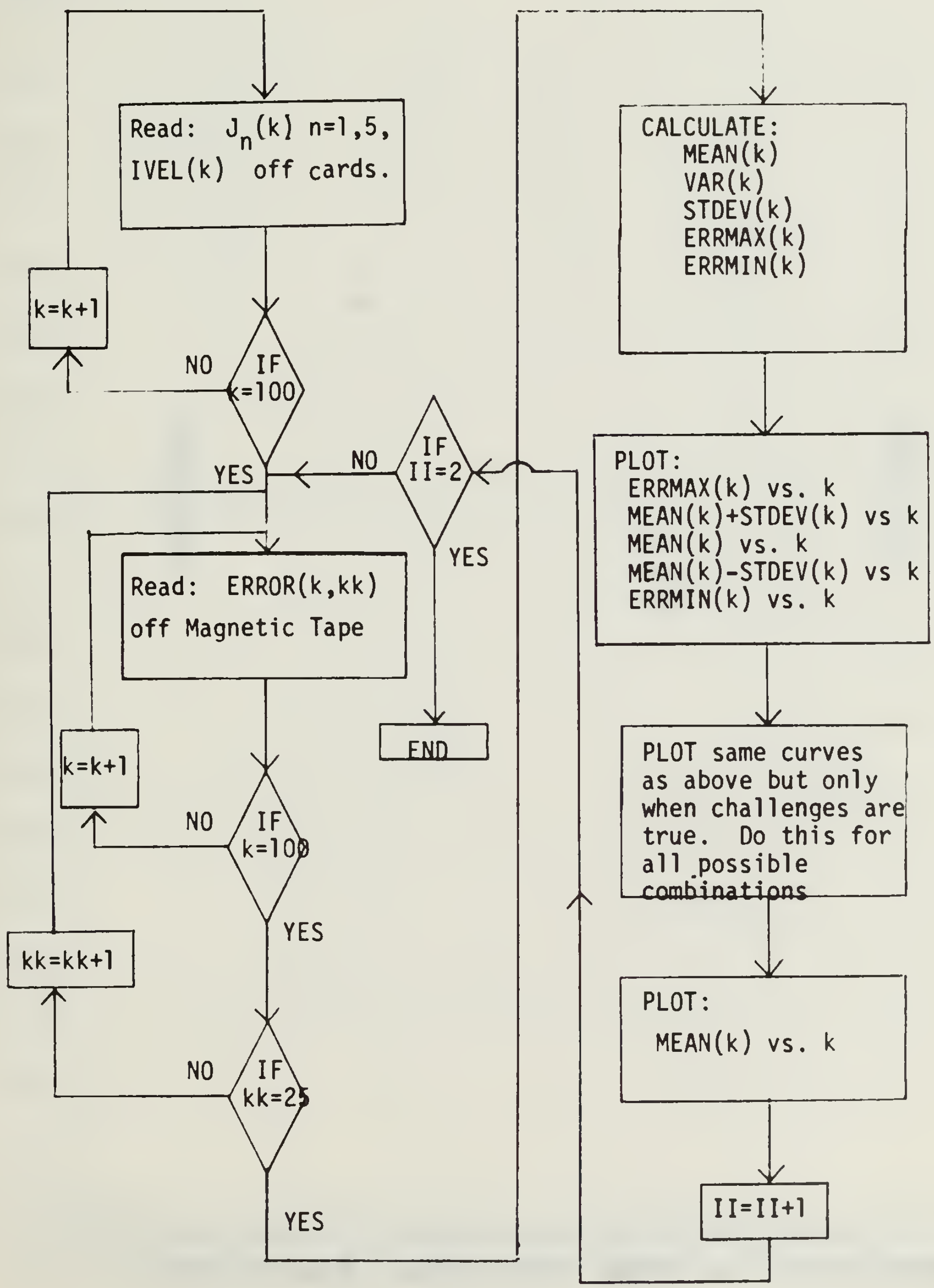


Fig. 9. FLOW CHART FOR PLOTTING GRAPHS

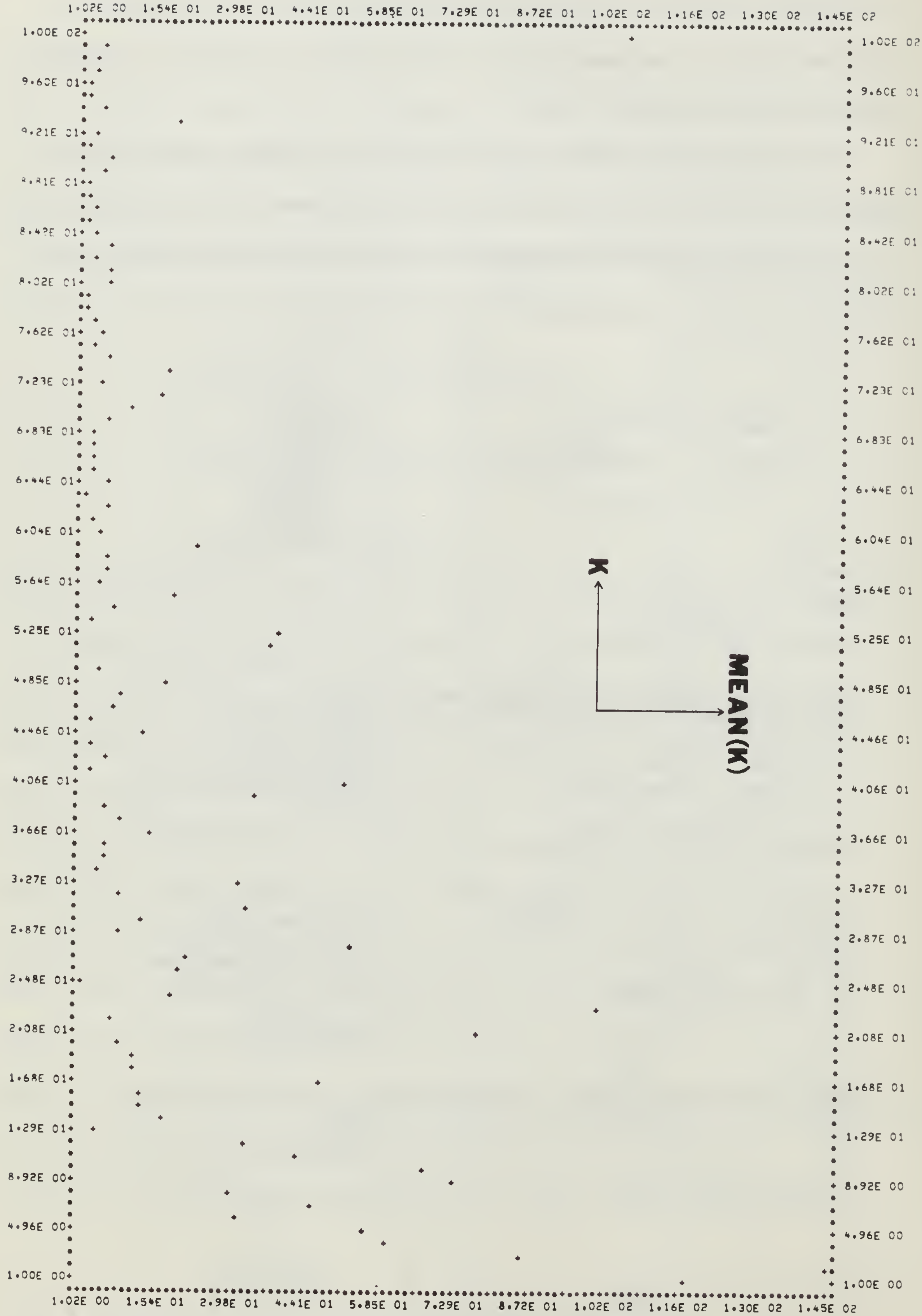


FIG.10 MEAN(K) VS. K FOR FAST-TIME SOLUTIONS

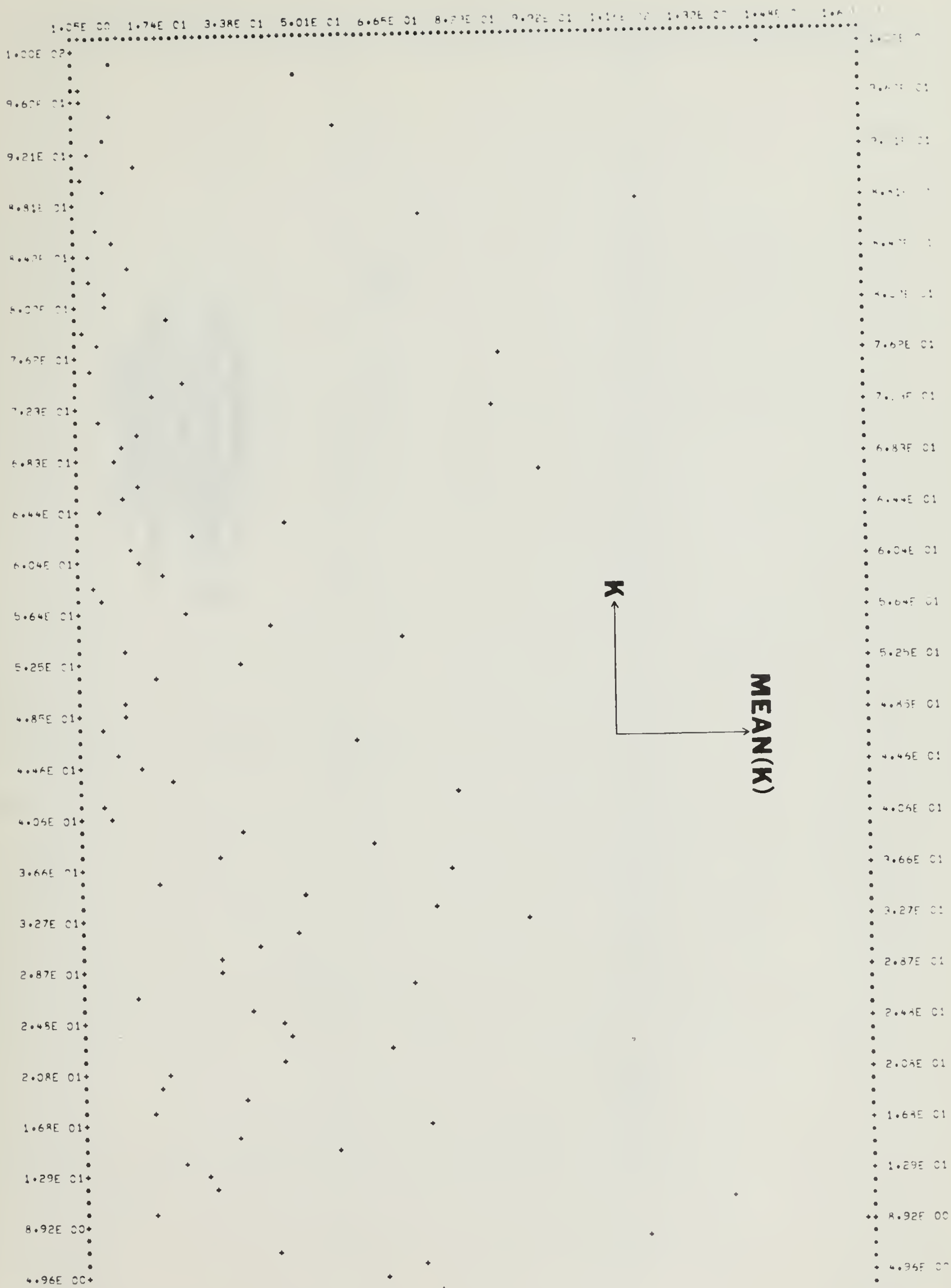


FIG.11 MEAN (K) VS. K FOR REAL-TIME-ONLY SOLUTIONS

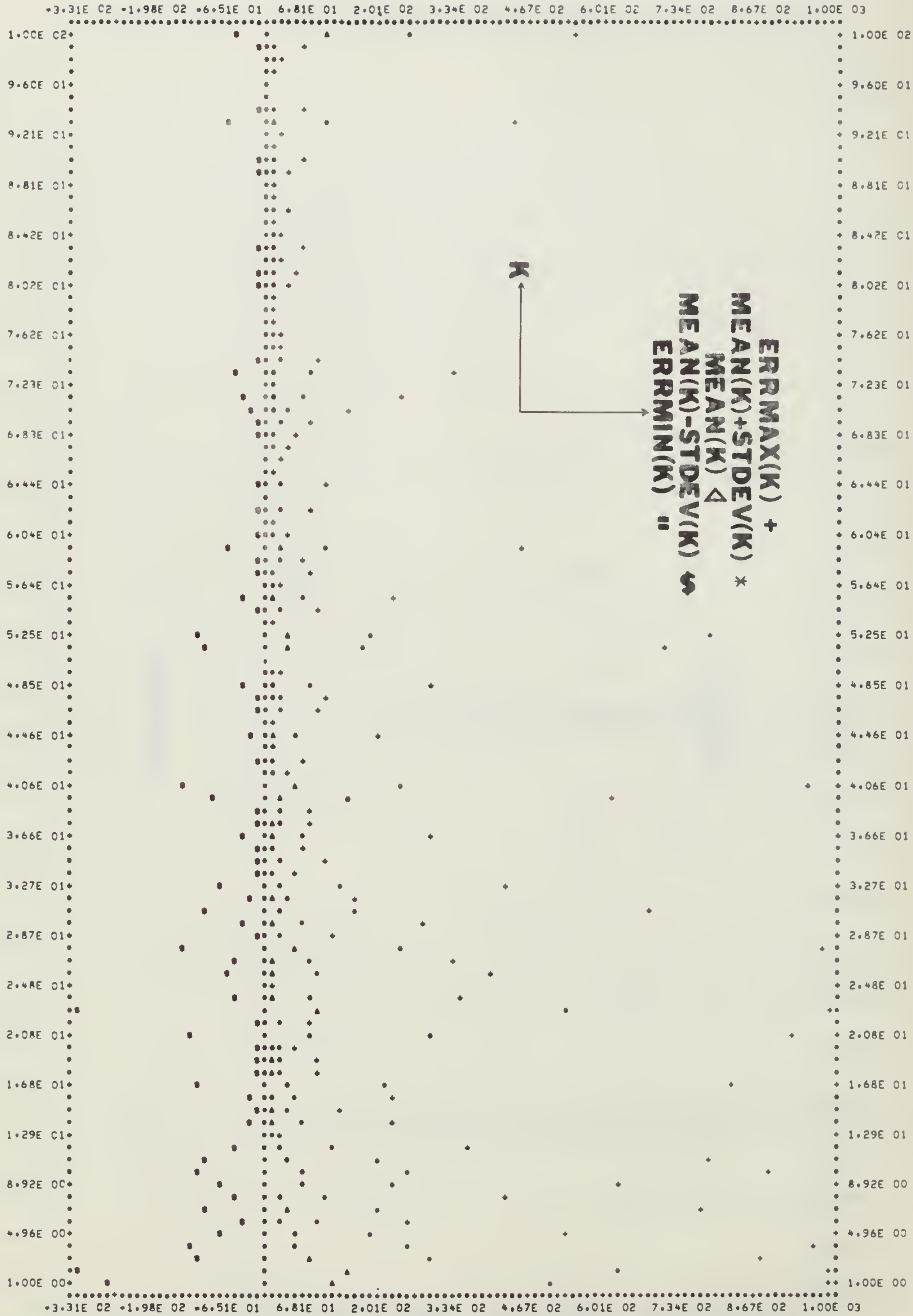


FIG. 12 COMPOSITE PLOTS FOR FAST-TIME SOLUTIONS

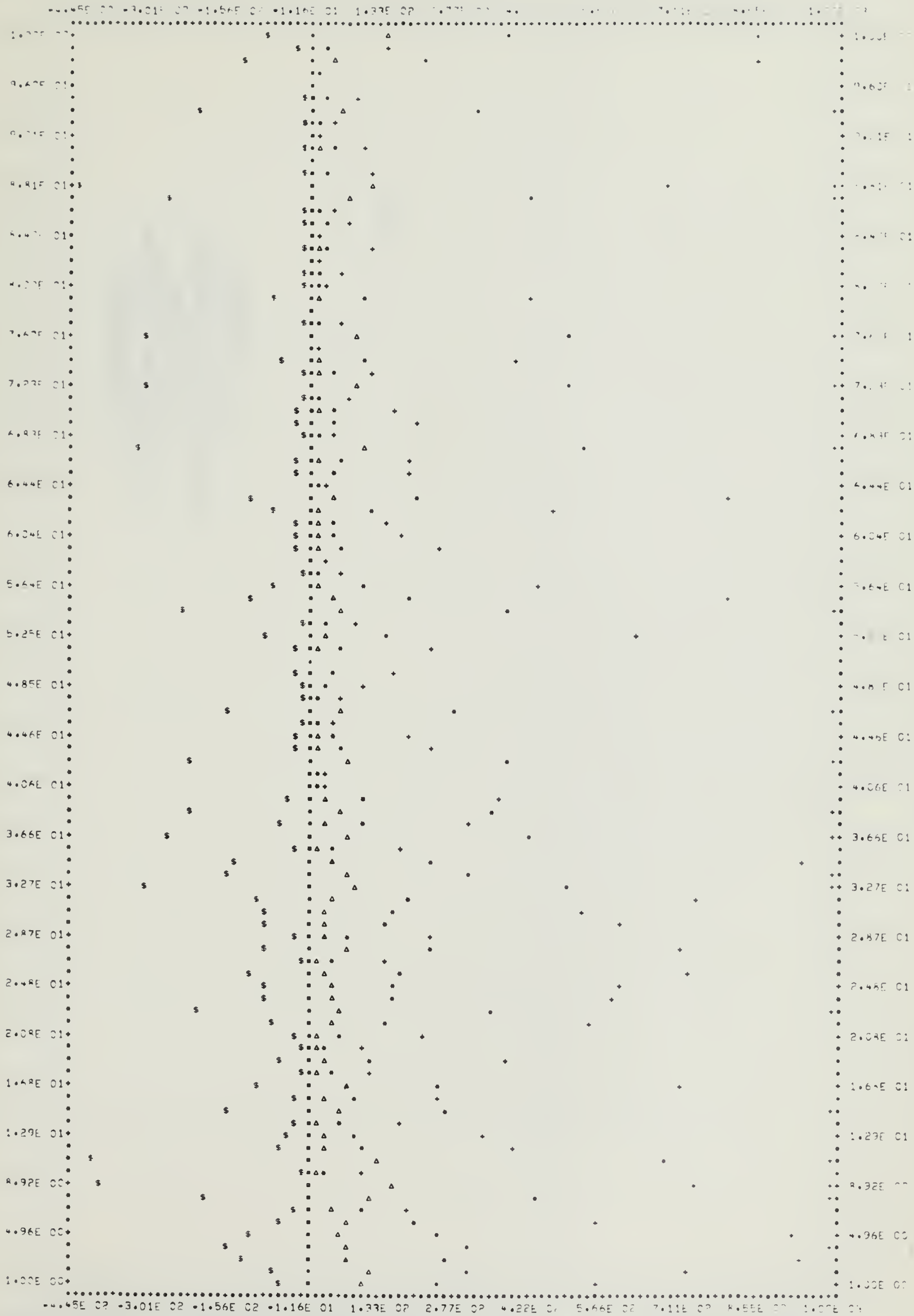


FIG. 13 COMPOSITE PLOTS FOR REAL-TIME-ONLY SOLUTIONS

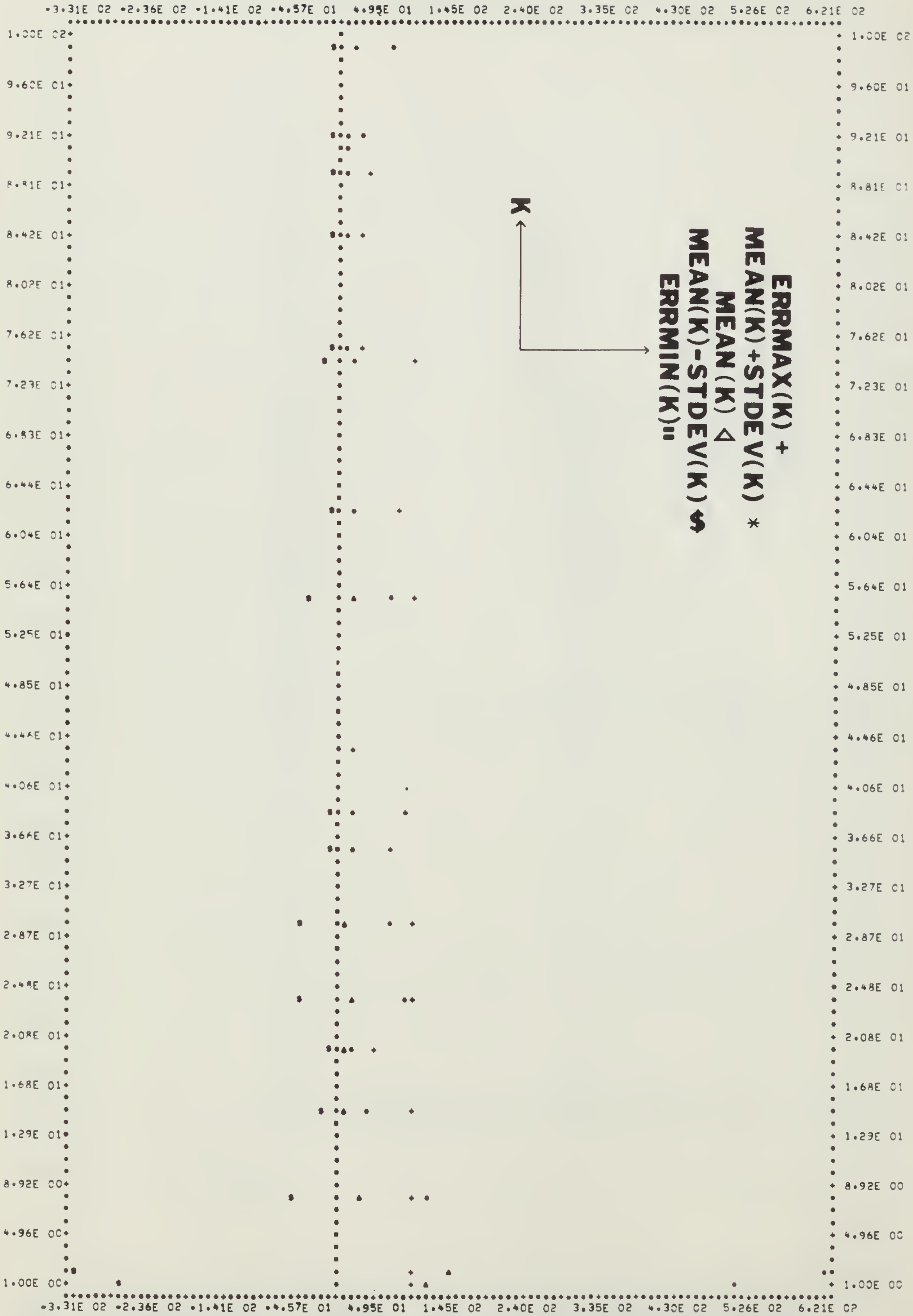


FIG.14 PLOTS FOR RUNS FROM SECTOR 5 (FAST-TIME)

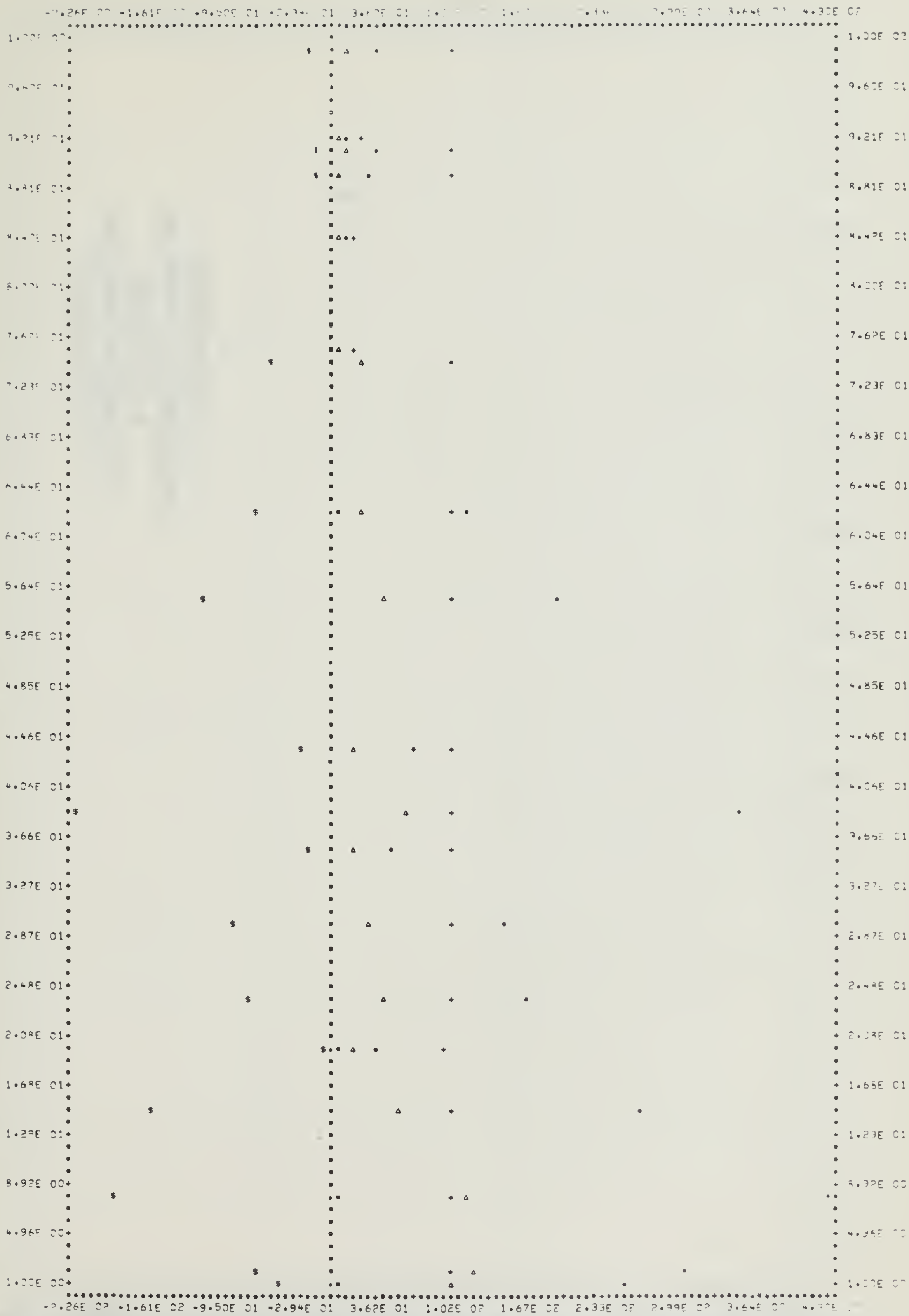


FIG.15 PLOTS FOR RUNS FROM SECTOR 5 (REAL-TIME-ONLY)

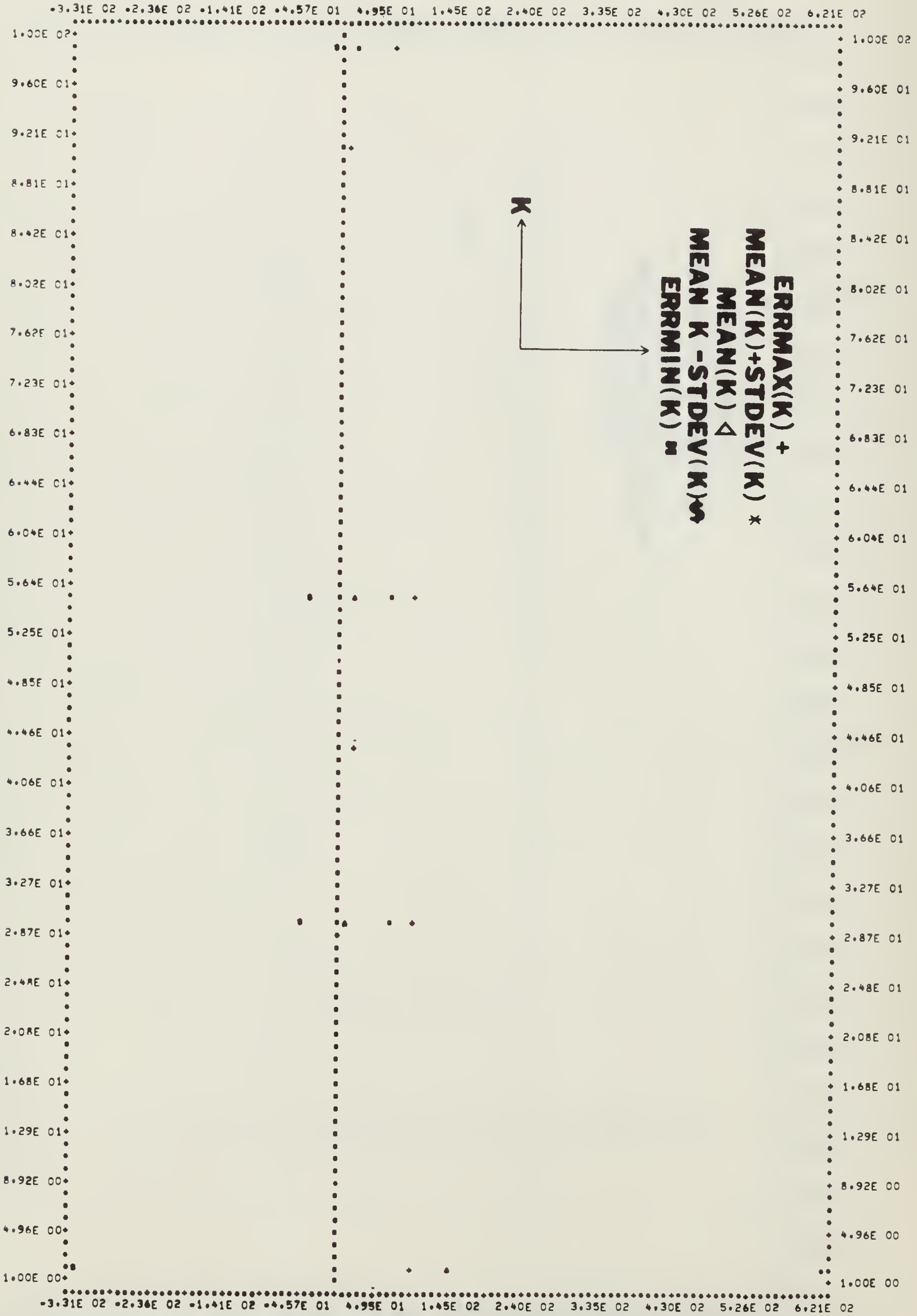


FIG.16 PLOTS FOR RUNS FROM SECTOR 5 (VELOCITY CHALL.) FT

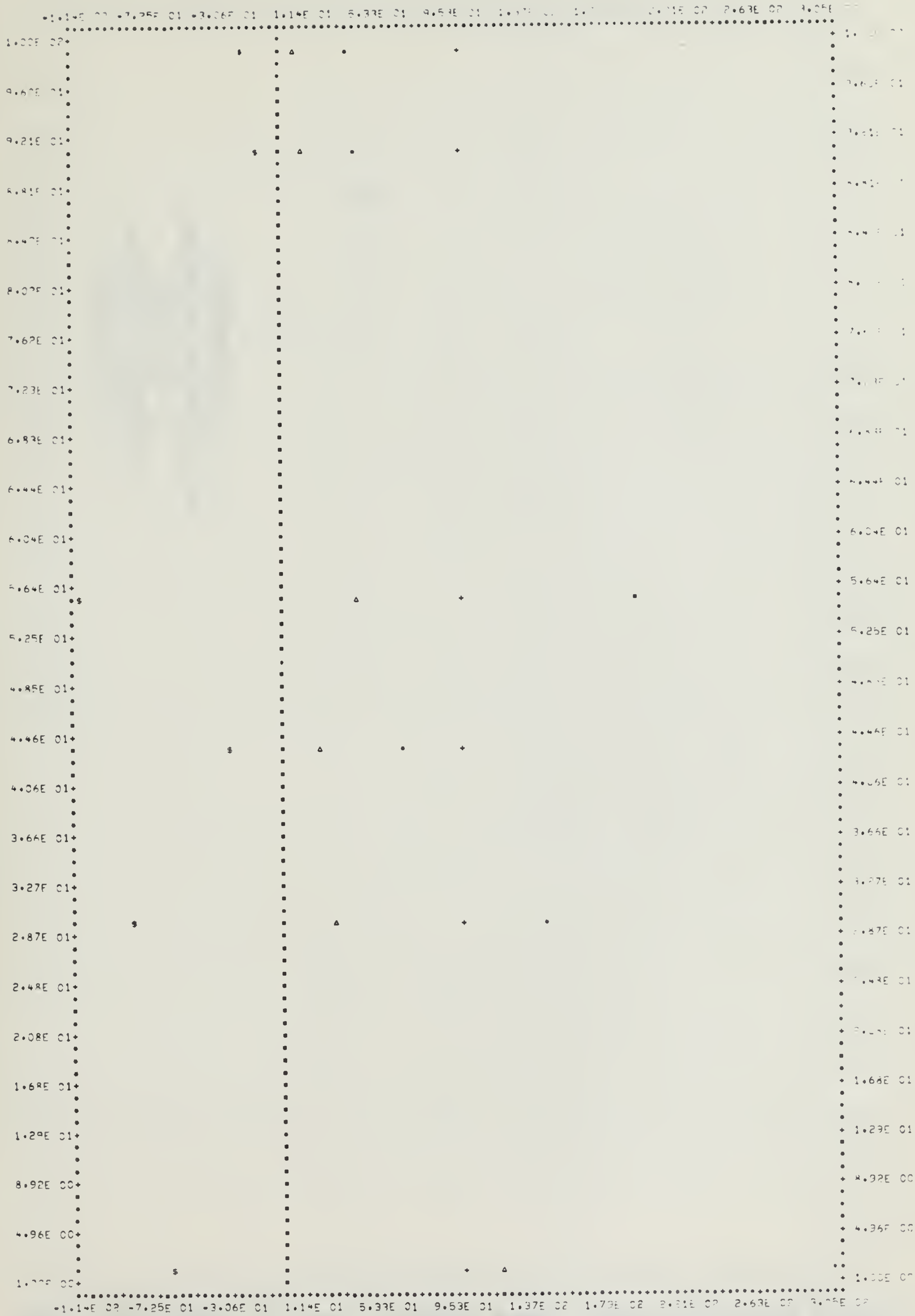


FIG.17 PLOTS FOR RUNS FROM SECTOR 5(VELOCITY CHALL. RTO)

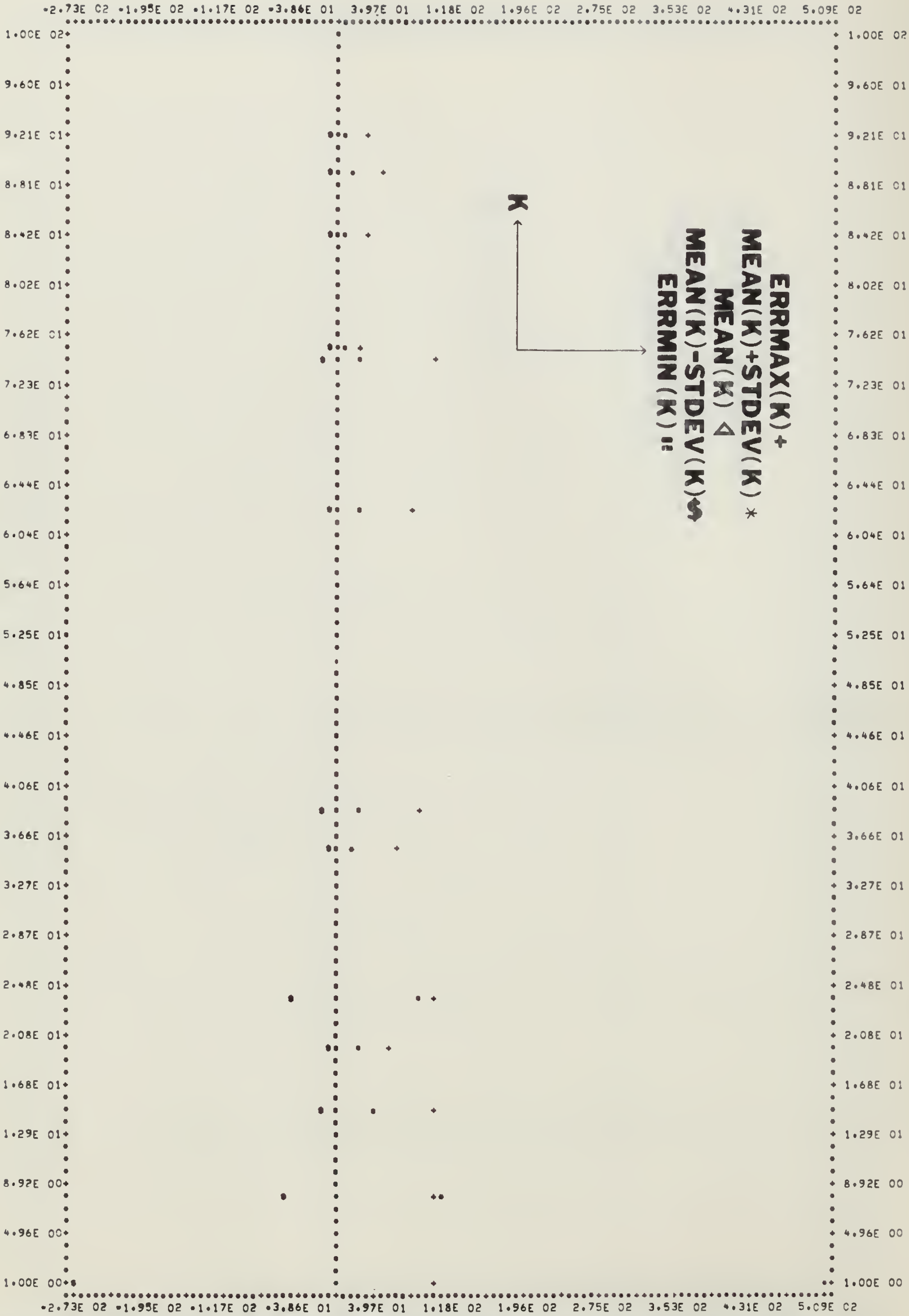


FIG.18 PLOTS FOR RUNS FROM SECTOR 5(NO VELOCITY CHALL. FT)

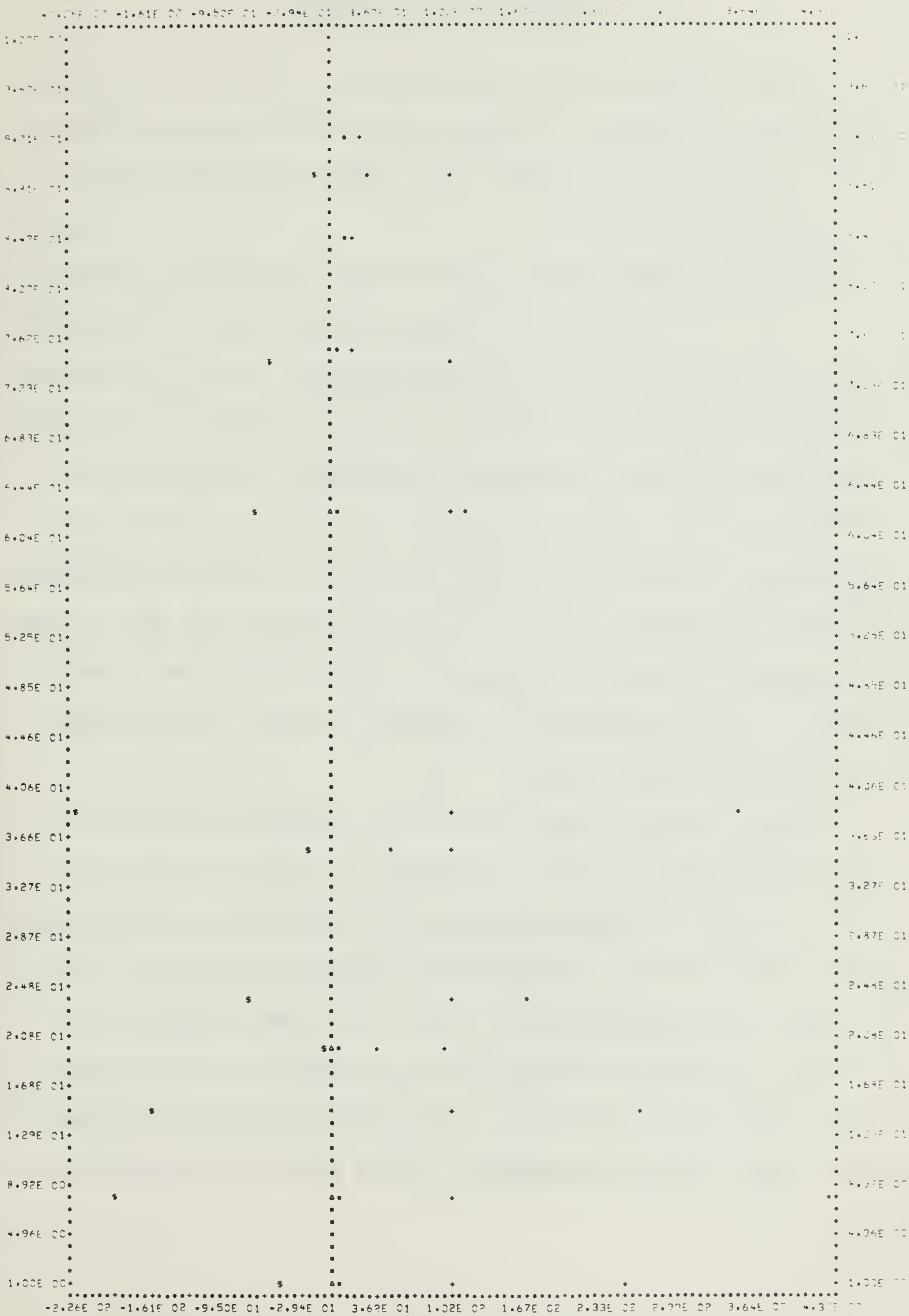


FIG. 19 PLOTS FOR RUN FROM SECTOR 5(NO VELOCITY CHALL. RTO)

VI. RESULTS OF DATA ANALYSIS

The two groups of graphs were compared to each other to see how the operators performed. The graphs within the groups were also compared to see what correlations, if any, could be derived from the various initial conditions.

The curves plotted without regard to initial conditions were examined first. The mean values for the operators who did not have the use of the predicted solutions were very erratic. They had essentially learned the system by run number 85, but even then five of the last 15 runs had mean values of greater than 50(MEAN(K)). The largest mean value was 165 on run nine. The standard deviation varied even more than the mean. During the first 50 runs, only 24 runs had a standard deviation less than 50. During the second 50 runs, there were 38 runs with a standard deviation less than 50. There were 19 runs in which the maximum error was equal to or greater than 1000. Seven of these were during the second 50 runs.

The human operators who had use of the fast-time solutions did considerably better than their counterparts. These operators had a training period of 60 runs. However, if it had not been for only four runs in which the mean value was greater than 50, the training would have been accomplished by run 30. The highest mean value was 145 on run two. The standard deviations were not spasmotic and consistently improved throughout the 100 runs. There were only three maximum errors greater than 60 after run number 60. These plots are illustrated in Figs. 10-19.

When only the velocity challenge was considered, the training periods for the fast-time solutions were the same no matter what the initial velocity was. The mean value and the standard deviation were approximately 50 percent greater when there was an initial velocity challenge. There was an increase in the training time when no predicted solutions were displayed however. The period was run 80 with a velocity challenge and 60 without the challenge.

Table 1 shows the approximate training times for the various combinations of position and velocity challenges. In every single case the training time for the predicted solutions was less than or equal to the training time of the real-time-only solutions. The biggest improvement was when the initial position challenge was in sectors four and five. The improvement was a great as 70 runs. There was also a very large difference in the standard deviation in these two sectors, the fast-time solutions being consistently small and the real-time-only solutions being large and erratic. The plots of runs starting from sector five are shown in Figs. 14-19 to more clearly illustrate the difference. In general all the fast-time solution standard deviations were considerably less than those for the real-time-only solutions, by an approximate factor of three.

The steady-state value of the post-training performance was less by a factor of two for the fast-time operators. The performance for these operators was also very steady with very little deviation in the mean value of the error. This was not true for the real-time-only operators.

TABLE I

SUMMARY OF TRAINING PERIODS

Challenge Sector	RTO All Cases	FT All Cases	RTO w/ velocity challenge	FT w/ velocity challenge	RTO w/o velocity challenge	FT w/o velocity challenge
1	70	35	60	59	55	35
2	42	30	65	30	30	20
3	65	50	70	55	50	50
4	90	45	*	*	90	40
5	85	15	100+	30	75	15

* INSUFFICIENT DATA FOR CONCLUSIONS.

VII. CONCLUSIONS

The human operators who had the use of predictive solutions were able to learn the control system sooner than operators who did not have the aid of such solutions. The decreased training time was even more pronounced when the initial challenge was greater.

This leads to the conclusion that the training of human operators can be greatly enhanced with predictive solutions. The decrease in improvement of the training period when the initial challenge was a lesser degree shows that for the predictive solutions to be worthwhile, the system must indeed be complex and slow in responding to the input.

The improvement in the steady-state performance when the predictive solutions were provided, indicates that the use of predictive solutions in production runs might be necessary in some cases. When consistency and precise accuracy are needed, the predictive solutions would prove to be of value even after training is completed. However, if expense and practicality are considered to be more important than precise performance, the fast-time solutions would not be needed. These conclusions depend on the system under consideration and no exact rule for the use of predictive solutions in productive operation can be drawn without further investigation in this area.

APPENDIX A

1. DISPLAY CIRCUITRY

The oscilloscope used for display to the human operator had only single X and Y inputs. In order to display two separate pieces of information simultaneously, it was necessary to use four digital-to-analog switches, summing junctions of two amplifiers, and two high-speed delay flops. Two more high-speed delay flops were input to a nand gate and its output went to the sweep-blank input of the oscilloscope. This eliminated the presence of a continuous trace line between the two solution spots on the scope face. The circuitry is shown in Figs. 2 and 5.

```
ΔASSIGN 2=MT1A,6=LP1A
ΔFØRTRAN LS,GØ
      DIMENSIØN ERRØR(100),J1(100),J2(100),J3(100),J4(100),J5(100),IVEL(
     1100)
      DIMENSIØN YD(26)
      DIMENSIØN JXY(100)
      DIMENSIØN D(100,2)
      WRITE(101,900)
  900 FØRMAT($SET SENSE SWITCH 6 FØR FILE SEARCH$)
      PAUSE
      IF(SENSE SWITCH 6)220,330
  220 REWIND 2
   98 CALL EØFSET(1000S)
   99 READ(2,199)
      GØ TØ 99
 1000 CALL EØFSET(1001S)
      READ(2,199)
      GØ TØ 98
 1001 BACKSPACE 2
  199 FØRMAT(F10.5)
  330 I1=0
      I2=0
      I3=0
      I4=0
      I5=0
      YAVG=0.0
      XAVG=0.0
      XVAR=0.0
      YVAR=0.0
      XSTDEV=0.0
      YSTDEV=0.0
      XVARCH=0.0
      YVARCH=0.0
      XVARAV=0.0
```

```
      YVARAV=0.0
      XDEVAV=0.0
      YDEVAV=0.0
      K=0
      P1=0.0100
      P26=.75
      P16=0.500
      CALL SETPØT(4HP001,P1,4HP026,P26,4HP016,P16)
      CALL RESET
    1 IF(TEST(1))2,2,1
    2 DØ 40 I=1,100
      K=K+1
      IVEL(K)=0
      J1(K)=0
      J2(K)=0
      J3(K)=0
      J4(K)=0
      J5(K)=0
      CALL RANDØM (W)
      IF(W.LT.0.0) GØ TØ 200
      GØ TØ 201
  200 W=-W
  201 W=W/10.0
      CALL DAC(1,W)
      CALL RESET
    3 IF(TEST(1))4,4,3
    4 W=W*100.
      XPØS=W
      WRITE(6,5)W
    5 FØRMAT(//$X(0)=$,F10.5)
      CALL RANDØM (W)
      IF(W.LT.0.0) GØ TØ 400
      GØ TØ 401
  400 W=-W
  401 W=W/80.0
```

```
      CALL DAC(2,W)
      CALL RESET
    6 IF(TEST(1))7,7,6
    7 W=W*100.
      YVEL=W
      WRITE(6,8)W
    8 FØRMAT( // $YDØT(0)=$,F10.5)
      CALL RANDØM (W)
      W=((W*2.0)-1)/80.0
   52 CALL DAC(3,W)
      CALL RESET
   53 IF(TEST(1))54,54,53
   54 W=W*100.
      XVEL=W
      IF(ABS(XVEL).GT.0.625.AND.YVEL.GT.0.625) GØ TØ 56
      GØ TØ 51
   56 IVEL(K)=1
   51 WRITE(6,55)W
   55 FØRMAT(//$XDØT(0)=$,F10.5)
      IF(XPØS.LT.1.0.ØR.XPØS.GT.9.0) GØ TØ 101
      GØ TØ 102
  101 I5=I5+1
      J5(K)=1
  102 IF(XPØS.LT.2.0.AND.XPØS.GT.1.0) GØ TØ 103
      GØ TØ 104
  103 I4=I4+1
      J4(K)=1
  104 IF(XPØS.LT.3.0.AND.XPØS.GT.2.0) GØ TØ 105
      GØ TØ 106
  105 I3=I3+1
      J3(K)=1
  106 IF(XPØS.LT.4.0.AND.XPØS.GT.3.0) GØ TØ 107
      GØ TØ 108
  107 I2=I2+1
      J2(K)=1
```

```
  108 IF(XPØS.LT.6.0.AND.XPØS.GT.4.0) GØ TØ 109
      GØ TØ 110
  109 I1=I1+1
      J1(K)=1
  110 IF(XPØS.LT.7.0.AND.XPØS.GT.6.0) GØ TØ 111
      GØ TØ 112
  111 I2=I2+1
      J2(K)=1
  112 IF(XPØS.LT.8.0.AND.XPØS.GT.7.0) GØ TØ 113
      GØ TØ 114
  113 I3=I3+1
      J3(K)=1
  114 IF(XPØS.LT.9.0.AND.XPØS.GT.8.0) GØ TØ 115
      GØ TØ 20
  115 I4=I4+1
      J4(K)=1
   20 CALL CØMPUTE
   16 IF(TEST(2))17,17,16
   17 CALL ADK(2,X,3,Y)
      X=X*100.
      Y=Y*100.
      WRITE(6,30)X,K
   30 FØRMAT(//$THE FINAL VALUE ØF X=$,F10.5,$   RUN NØ. $,I4)
      WRITE(6,31)Y
   31 FØRMAT( // $THE FINAL VALUE ØF Y=$,F10.5)
      XAVG=XAVG+X
      YAVG=YAVG+Y
      XVAR=(X-5.0)**2
      YVAR=(Y-10.0)**2
      ERRØR(K)=XVAR+YVAR
   40 CØNTINUE
      XAVG=XAVG/100.0
      YAVG=YAVG/100.0
      WRITE(6,41)XAVG
   41 FØRMAT(//$1THE AVERAGE VALUE ØF X=$,F10.5)
```

```
      WRITE(6,42)YAVG
   42 FØRMAT(//$THE AVERAGE VALUE ØF Y=$,F10.5)
      WRITE(6,77)
   77 FØRMAT(//$ERRØR(K)=$,10X,$J1(K)=$,4X,$J2(K)=$,4X,$J3(K)=$,4X,$J4(K
     1)=$,4X,$J5(K)=$,4X,$IVEL(K)=$)
      WRITE(6,78),(ERRØR(K),J1(K),J2(K),J3(K),J4(K),J5(K),IVEL(K),K, K=1
     1,100)
   78 FØRMAT(/F10.5,8X,I3,4X,I3,4X,I3,4X,I3,4X,I3,4X,I3,4X,I3)
      WRITE(  6,79)I1,I2,I3,I4,I5
   79 FØRMAT(///$THERE WERE$,I6,$,$,I6,$,$,I6,$,$,I6,$,$,I6,$ RUNS MADE
     1FRØM AREAS1,2,3,4,5, RESPECTIVELY.$)
      WRITE(2,210),(ERRØR(K), K=1,100)
  210 FØRMAT(1X,F10.5)
      DØ 700 K=1,100
      D(K,1)=K
      D(K,2)=AMIN(ERRØR(K),100.0)
  700 CØNTINUE
      JXY(1)=2
      JXY(2)=1
      CALL LØNGPLØT(D,JXY,100,100,1,0,0.0,0.0,0.0,0.0,25,YD)
      END FILE 2
      IF(SENSE SWITCH 6)150,160
  150 END FILE 2
  160 STØP
      END
```

```
END OF COMPILATION
      SUBROUTINE RANDOM (W)
      DIMENSION R(30)
      DATA I/10/
      DATA  R/
     C   .150781319000088,   .914453206998587,   .514453231837251,
     C   .898828280478483,   .815625252795143,   .612891073171340,
     C   .838672715504799,   .397655462456896,   .273045296104100,
     C   .800387462008075,   .779681167623493,   .810924827368580,
     C   .094115270407201,   .029246154575957,   .416304796039185,
     C   .855265827125549,   .546078512492385,   .888641380963235,
     C   .682751490840018,   .528002958235447,   .623584015538654,
     C   .367871127691614,   .557617224250861,   .786328164656879,
     C   .241015667790634,   .295703170922934,   .698437549086520/
C     THESE VALUES WERE OBTAINED BY RUNNING THE OLD SELF-INITIALIZING
C     VERSION OF RANDOM 100 TIMES AND TAKING THE RESULTING VALUES IN R
C     THIS VERSION NEVER USES ITS ARGUMENT AS AN INPUT, AN ADDITIONAL
C     SAFEGUARD. RANDOM PRODUCES VALUES BETWEEN 0 AND 1.
    2 J=I
      I=I+1
      IF(I .GT. 30) I=1
      W=R(J)-R(I)
      IF(W .LE. 0.0) W=W+.999999999837
      R(I)=W
      RETURN
      END
```

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13. ABSTRACT

The effect of predictive solutions on human operator training time and post-training performance in a complex manual control system has been investigated. A control system with a slow and complex response to the input signals was formulated. Fifty operators, 25 with aid of predictive solutions and 25 without the predictive solutions, were tested and the mean performance of each group was compared to that of the other.

There was a significant improvement in the training time when the predictive solutions were provided. The improvement was directly proportional to the complexity of the system. The greater the initial challenge of the system, the greater was the worth of the predictive solutions. The post-training performance was better by a factor of two when the predictive solutions were available to the operator. The performance of the operators without the aid of predictive solutions remained inconsistent even after a steady-state performance had been reached.

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